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Beam stacking at KURNS

Shinji Machida
UKRI/STFC Rutherford Appleton Laboratory

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KURNS beam stacking

- Accelerate 1st bunch to final energy E1
- Debunch adiabatically the 1st bunch
- Characterise the coasting beam (momentum spread with empty bucket?)
- Recapture the coasting beam, measure it, redebunch it
- Measure the interference of the accelerating RF (no beam) on the coasting beam
- Inject & accelerate a second bunch to E2<E1
- Debunch adiabatically the second bunch
- Characterise the coasting beam
- Recapture the resulting total beam
- Measure the beam

One coasting beam and an empty bucket (step 2)

Subject	Preparation	Measurements
After debunching at E1, increase RF voltage with frequency at several points between injection and E1.	• Simulation to see how the coasting beam is affected. • When E1 is increased and RF frequency ratio approach 2, how quickly interference grows?	• dp/p measurement vs time (time scale should be determined by simulation) • Transverse beam profile measurement
Increase the energy of an empty bucket and adiabatically decrease voltage as if the beam is accelerated and debunched.	• Simulation to see how the coasting beam is affected.	• dp/p measurement • Transverse beam profile measurement
(optionally) rebunch the coasting beam	• Same with one bunch	• Beam intensity measurement • Longitudinal tomography measurement • Transverse beam profile measurement

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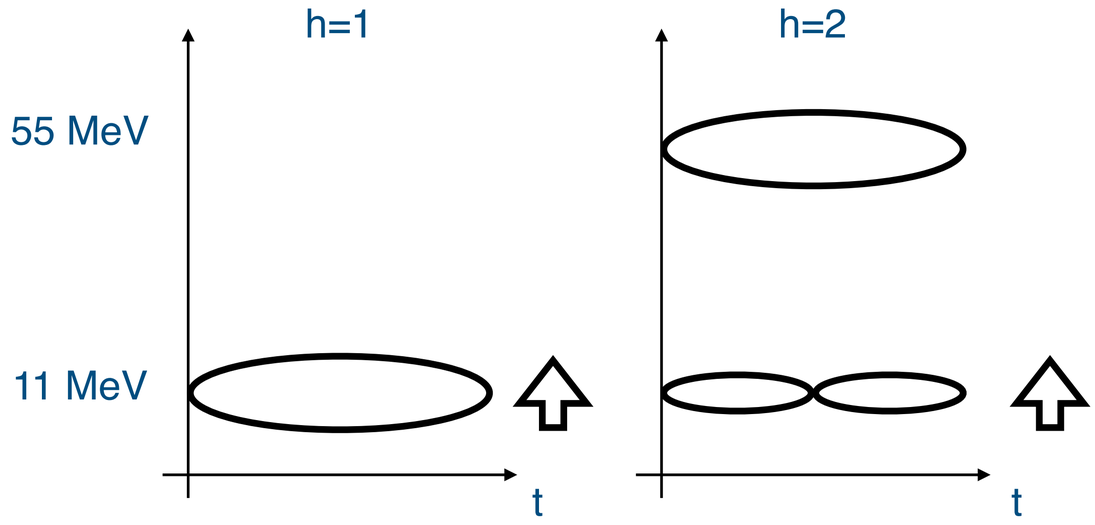
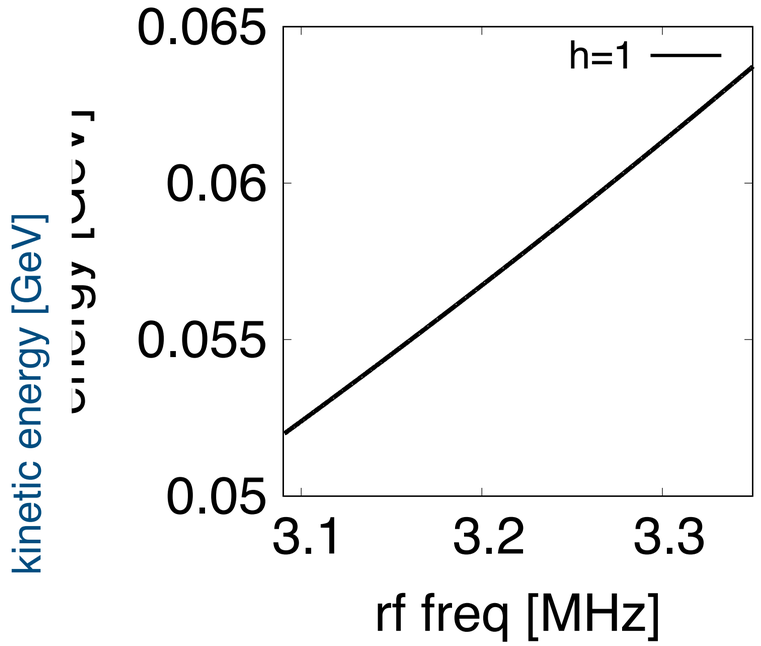
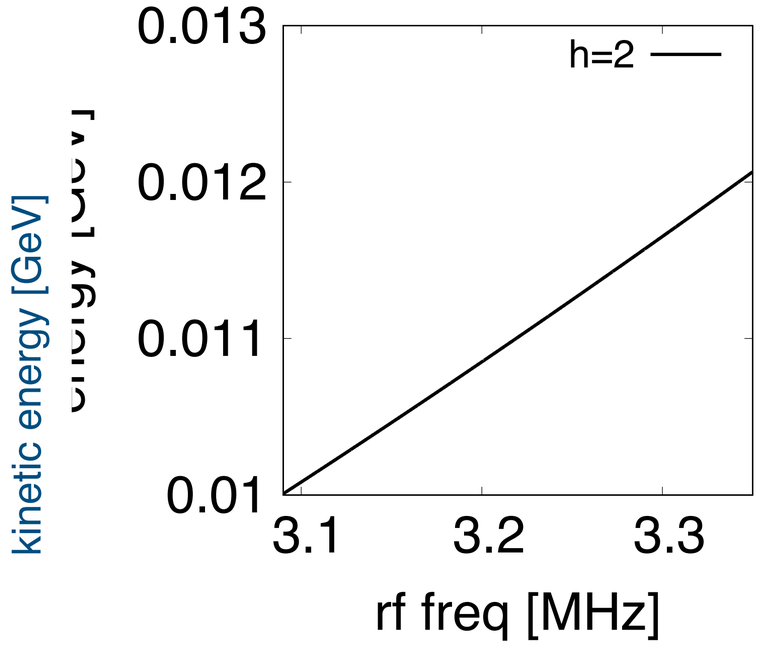
Setting up



- “accelerate” an empty bucket either with h=1 or 2 RF frequency.
  - phis = **20 degree**, voltage = 4 kV.

- RF frequency with h=2 at injection.
  - h=2 at ~11 MeV
  - h=1 at ~55 MeV (not at 44 MeV due to horizontal excursion.)





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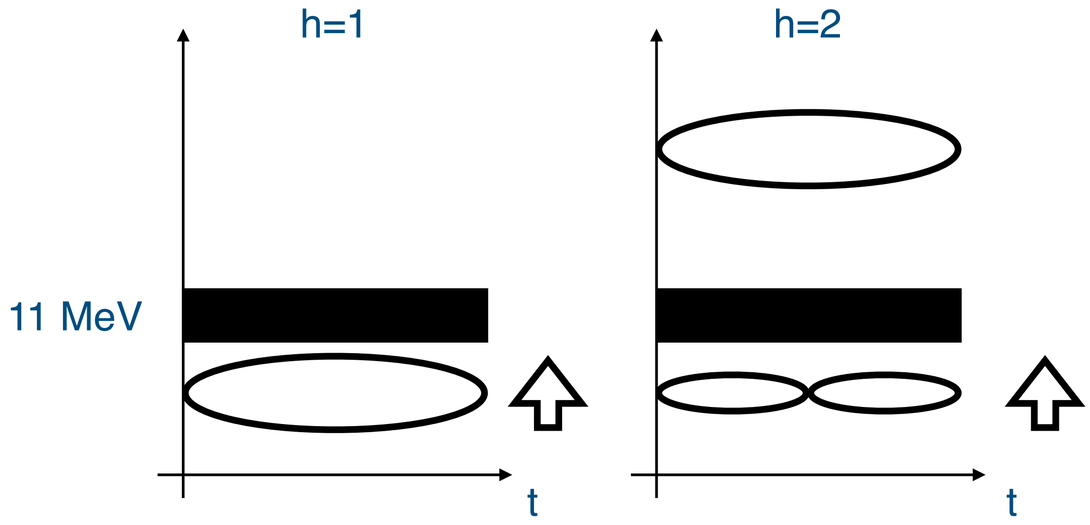
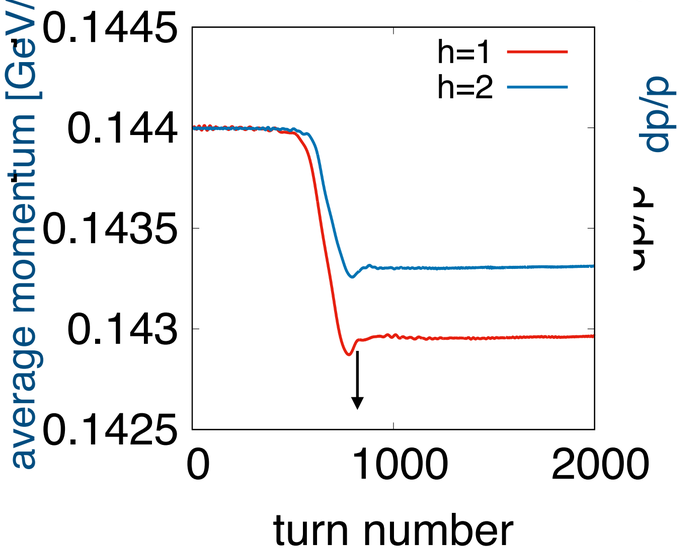
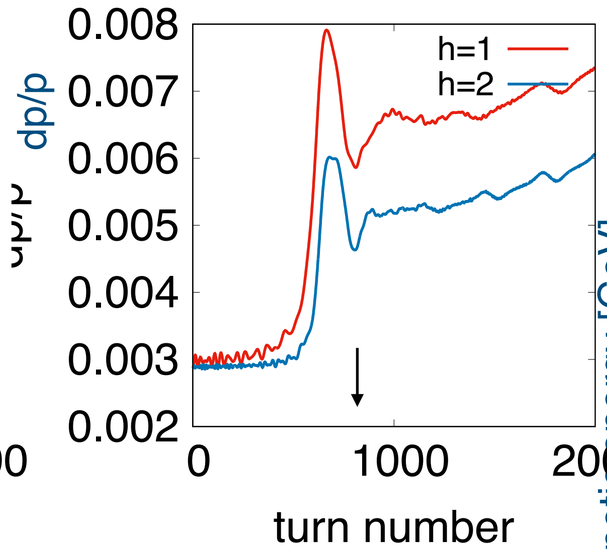
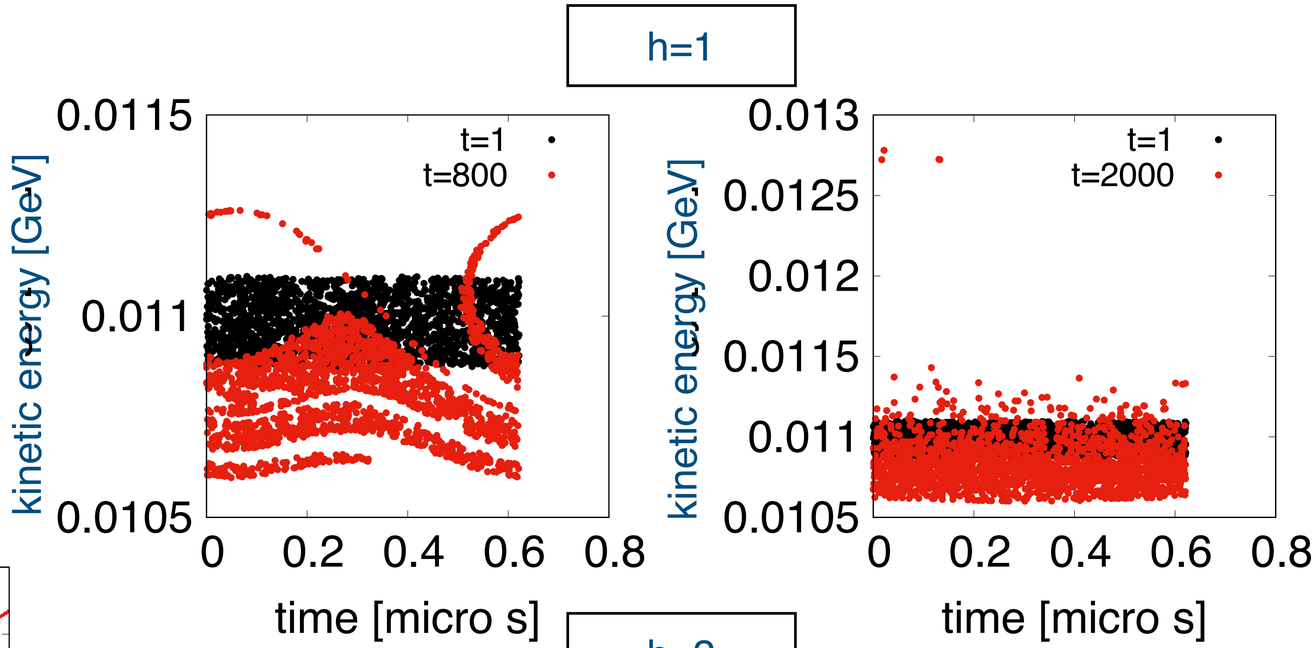
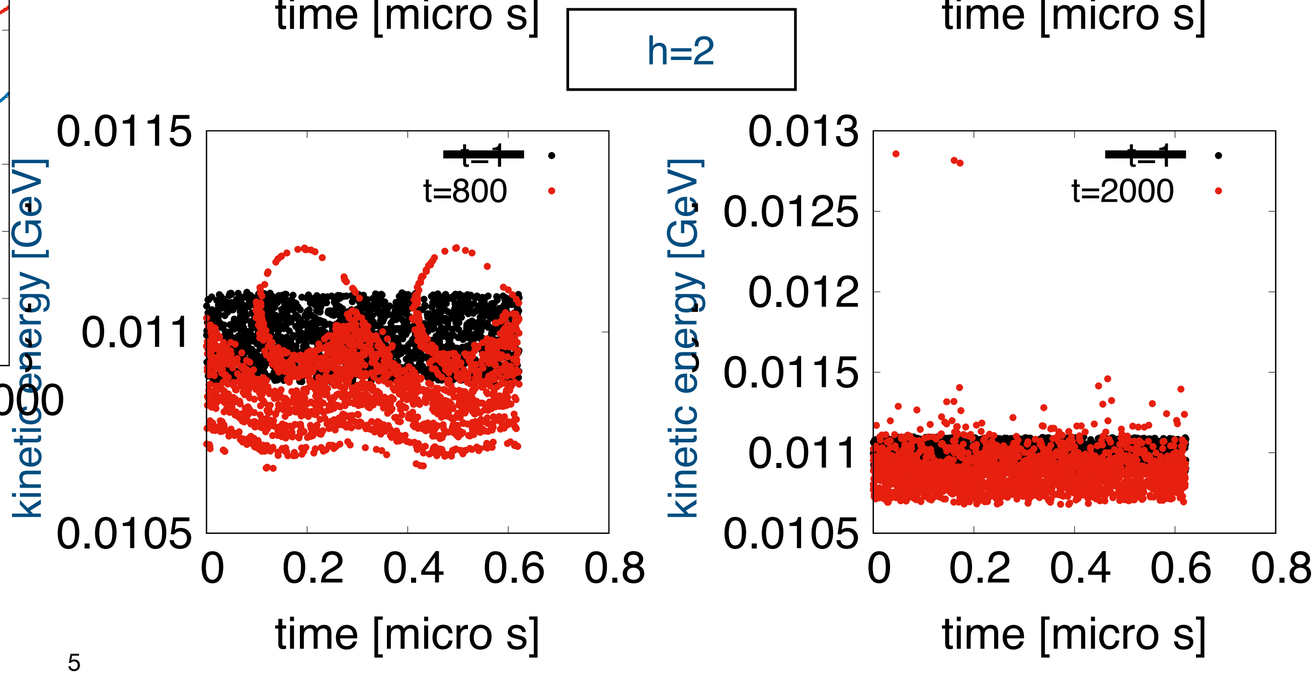
Effects on coasting beam at injection energy (11 MeV)











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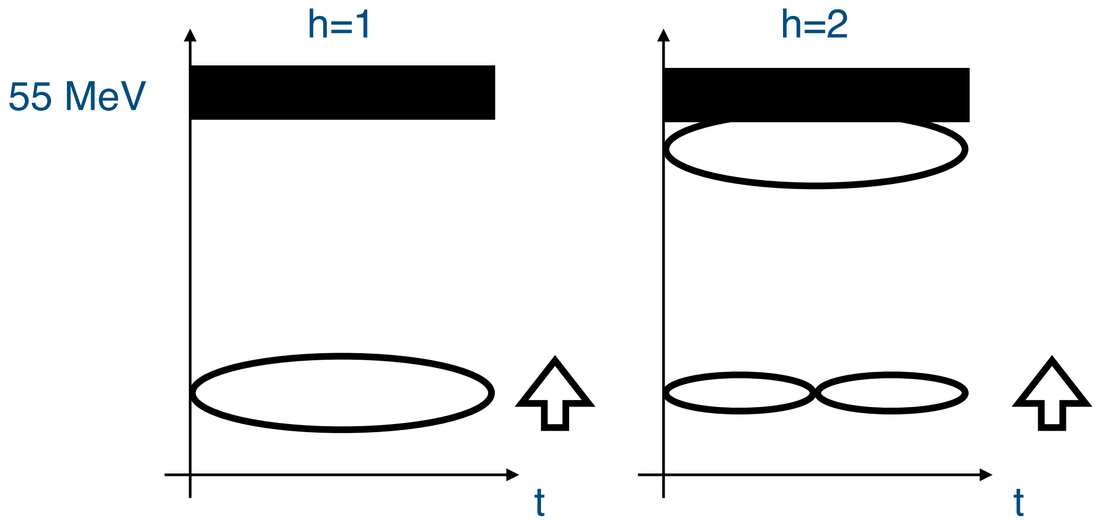
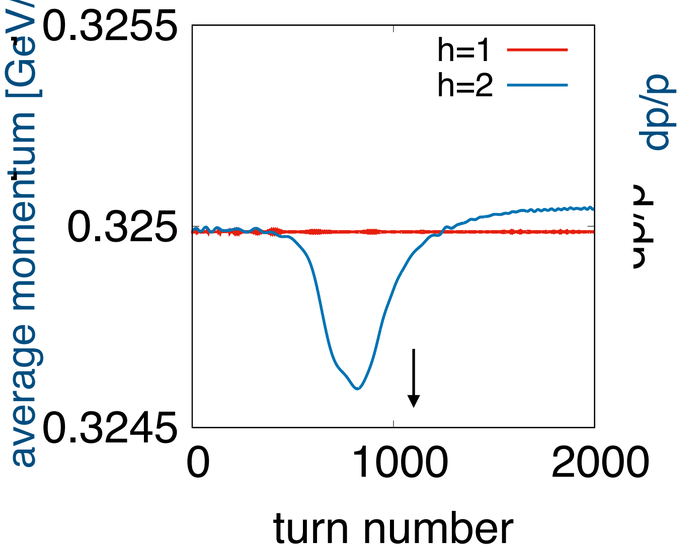
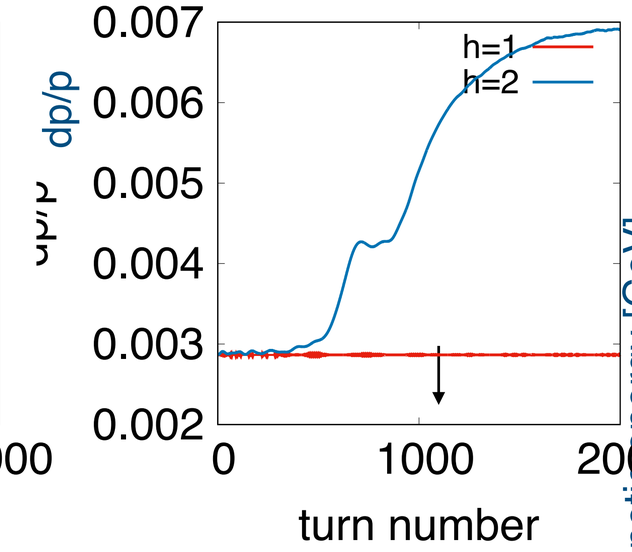
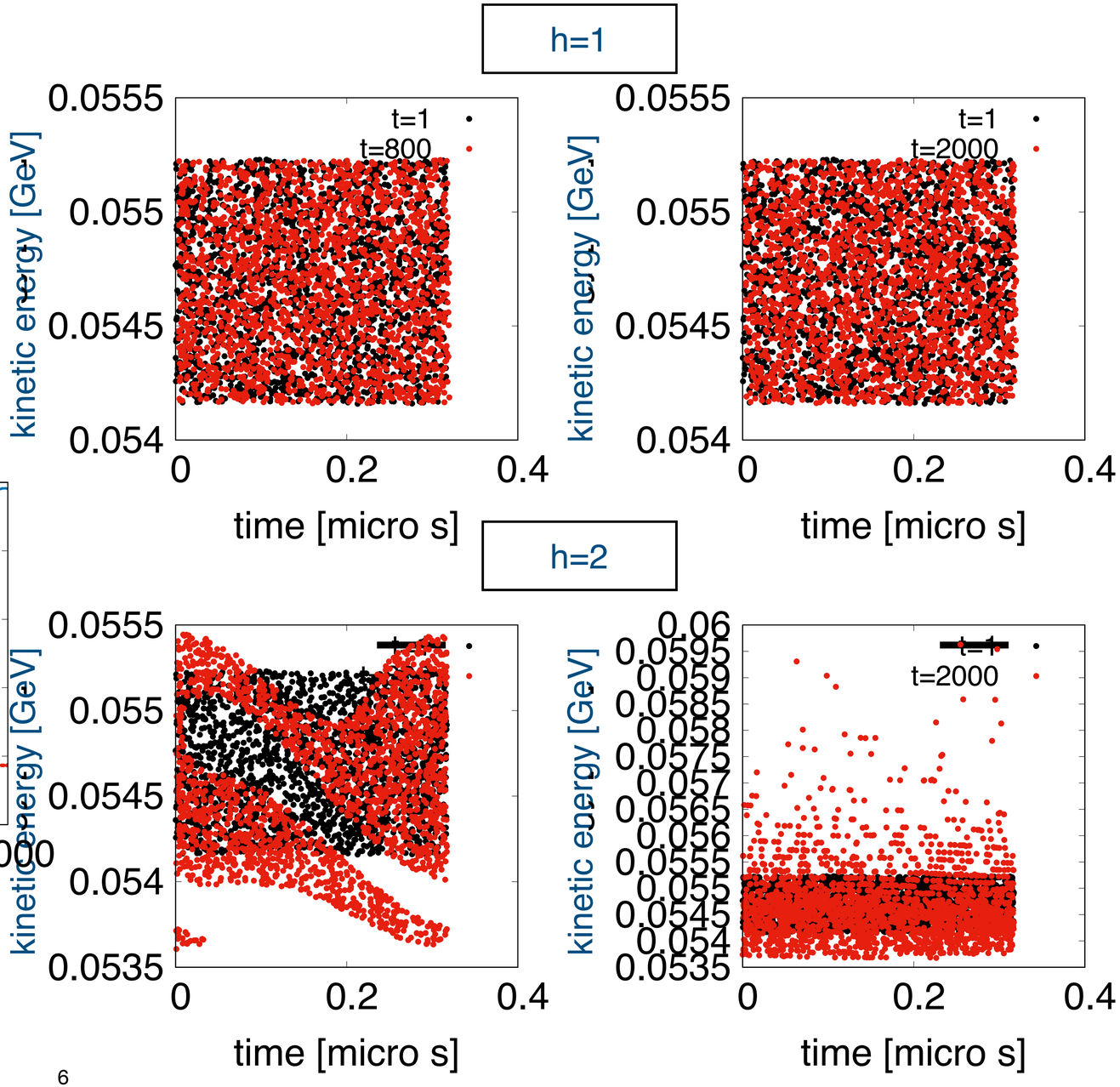
Effects on coasting beam at higher energy (55 MeV)









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Revised plan

- h=1 rf does not affect stacked beams.
  - Normal operation of KURNS main ring does not show interference.

- After accelerating the beam with a h=1 bucket and debunching,
  - “accelerate” an empty bucket of h=2.
  - Hopefully enough shunt impedance of the cavity to 2 x 3.2 MHz.
    - Normal range of RF frequency is 1.6 to 5.2 MHz.

- Request to Ishi-san. Is it possible to capture and accelerate the beams with h=2?

Parameters

Radius	4.54 m
RF frequency	1.6 ~ 5.2 MHz
Revolution time	0.625 ~ 0.192 micro s
Beta (11 MeV, 18 MeV)	0.1518, 0.1931 (ratio=1.27)
Beta (11 MeV, 47 MeV)	0.1518, 0.3052 (ratio=2.01)
Beta (0.4 GeV, 1.2 GeV)	0.7131, 0.8986 (ratio=1.26)

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Backup

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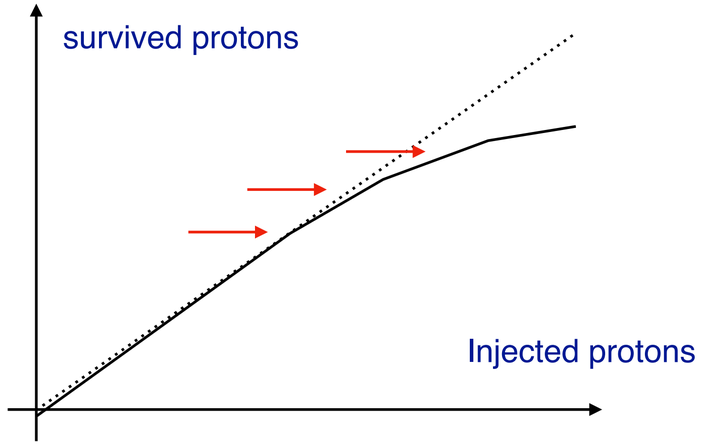
Milestones of the FETS-FFA project is to answer …

1. How many protons can we **accumulate** without beam loss at injection?	2. How many protons can we **accelerate** without beam loss to the top energy?
3a. How many protons can we **accumulate** without beam loss **by beam stacking** at the top energy?	3b. How many protons can we **capture** and **extract** without beam loss **after beam stacking**?



- We will define the meaning of “without beam loss” later (e.g. 5%, 1%, or 0.1%).
- It depends on diagnostics, stability of the hardware, injector (FETS) performance, etc.

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- Debunch adiabatically the second bunch
- Characterise the coasting beam
- Recapture the resulting total beam
- Measure the beam

One bunch only

Subject	Preparation	Measurements
Debunch adiabatically the 1st bunch	• Determine RF profile (frequency and voltage) to minimise dp/p after debunch	• dp/p measurement • Transverse beam profile measurement
Rebunch the coasting beam	• Determine RF profile (frequency and voltage) to minimise longitudinal emittance	• Beam intensity measurement • Longitudinal tomography measurement • Transverse beam profile measurement
Repeat debunch and rebunch process	• Same above	• **Beam intensity**, **dp/p** increase at debunch, **longitudinal emittance** increase at rebunch and **transverse beam profile** increase vs. the number of process

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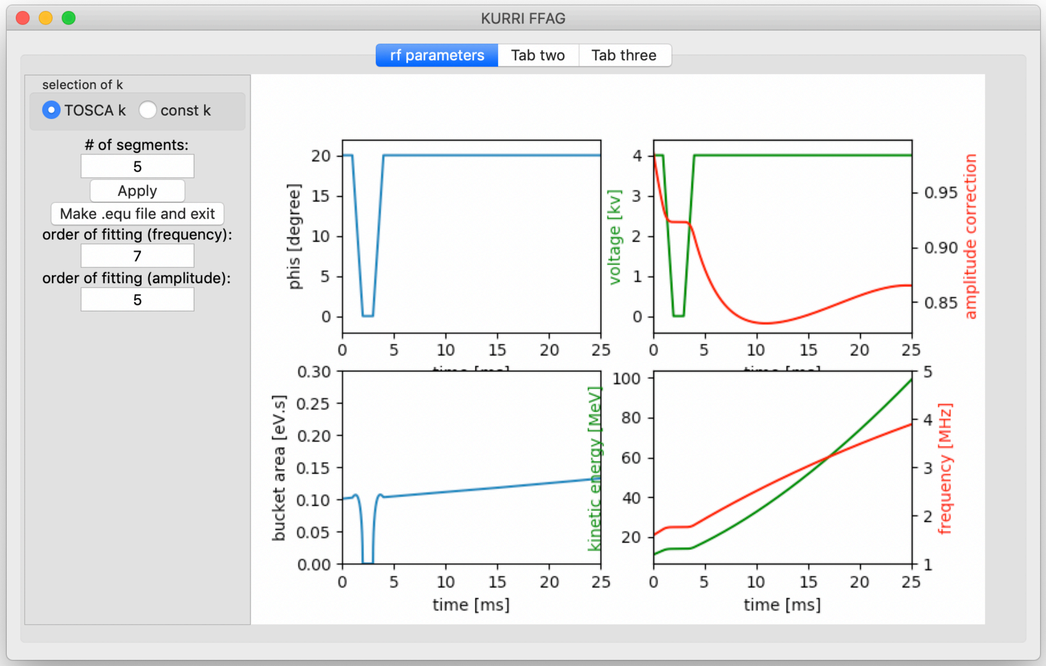
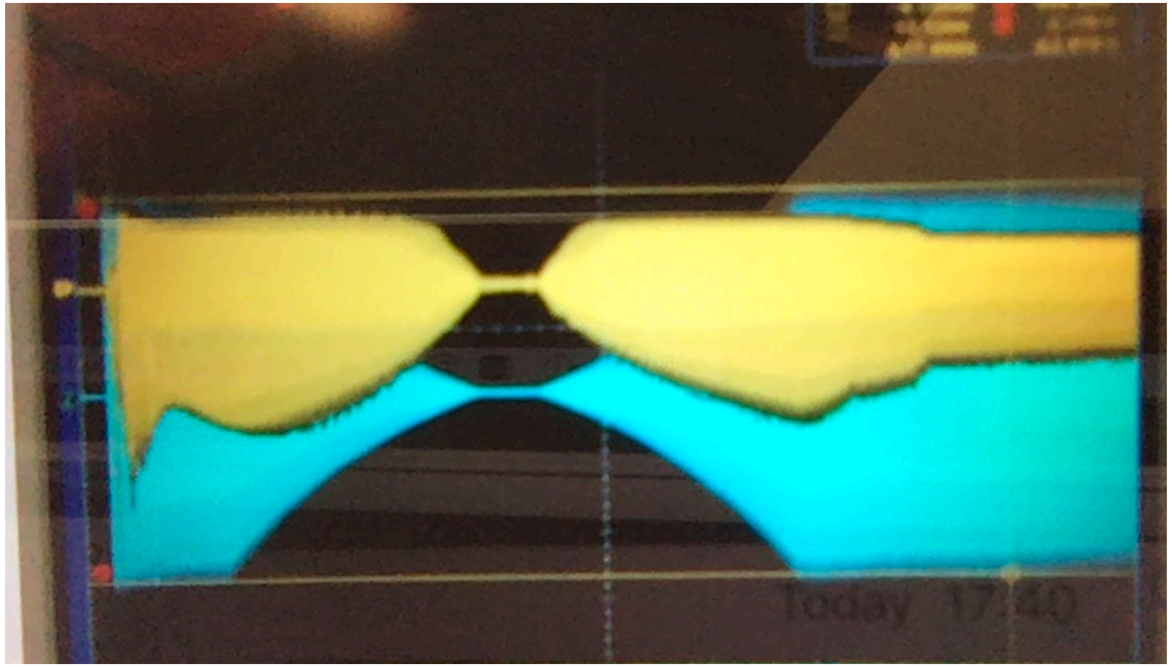
RF script and bunch monitor signal from 2019 experiment





yellow: bunch monitor

blue: RF signal

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- Debunch adiabatically the second bunch
- Characterise the coasting beam
- Recapture the resulting total beam
- Measure the beam

One coasting beam and another accelerating beam

Subject	Preparation	Measurements
Increase the energy of the 2nd beam and adiabatically decrease voltage.	• Simulation to see how the coasting beam is affected and the 2nd beam is added.	• dp/p measurement • Transverse beam profile measurement
Rebunch the coasting beam from two acceleration.	• Determine RF profile (frequency and voltage) to minimise longitudinal emittance	• Beam intensity measurement • Longitudinal tomography measurement • Transverse beam profile measurement
Repeat debunch and rebunch process (similar to measurement with one bunch but different dp/p)		• **Beam intensity**, **dp/p** increase at debunch, **longitudinal emittance** increase at rebunch and **transverse beam profile** increase vs. the number of process

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Before the experiments

- A lot of simulation study to optimise RF profile for debunch, rebunch and merging.
- Prepare AWG input to operate the RF cavity as we want.
    - Need to talk to Uesugi-san or Ishi-san to see the details of the present RF system.

- More discussion and study on how to measure dp/p. Unless we have a good idea, the entire experiment is not useful.
- Other measurements are possible in principle, but can be improved.

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